RESPONSE SPECTRUM OF STRONG EXPLOSION SEISM AND SEISMIC FORCE CALCULATION UNDER LINEAR CHARGE

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Abstract

In This paper, acceleration response spectrum of neer-field strong explosion seism under linear charge ($l/d \leqslant 20$, l, d — length and diameter of linear charge)and calculation method for seismic force are given according to the explosion seismic acceleration date measured at near-field in the media of granite, conglomerate and yellow soil, and date of building response measured from single-storey and multi-storey buildings.

Keywords: acceleration response spectrum of explosion seism, seismic force of explosion.

1. FORWORDS

In the field of damage analysis and safety evaluation of seismic effect caused by explosion on the building, the best relativity is exisiting between maximum perpendicular speed of earth surface and damage of buildings, and the stresses are provided by wave propagating within medium. The perpendicular speed of vibration of earth surface is adopted as standard evaluation by China and most of other countries. Actual data indicate that single layer reinfoce concrete workshop under $v_\perp < 25$ cm/s or single layer brick buildings under $v_\perp < 15$ cm/s appear no such damages which are able to influence the safety of buildings and that civil buildings(including multi-storey and high-rise buildings)under $v_\perp \leqslant 5$cm/s cause only cracking and falling of root mortar. This kind of evaluation of seismic effect of explosion is satisfactory in engineering practice in far-field. As the method posseses only one control index, it is impossible to consider the influences of properties of explosion source (quantity of explosion, shape of charge, characteristics of explosion), geological conditions of explosion field and buildings, and dynamic feartures of builgings (size, material, structure), so, the evaluation results are rather macroscopic and rough, and can't be used for satisfactory design of proof seism of explosion. In order to work out the calculating method of seismic force of explosion, some numerical technique such as finite element method may be used and also response

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spectrum of natural earthquake may be used for calculating the response spectrum of explosion seism and then makes a dynamic analysis to buildings.

up to now as to the knowledge of the authors, no research report or paper has been found both in China and abroad, which dealt with accelerate response spectrum of near-field explosion seism for linear charge ($l/d < 14$—20, l, d—length and diameter of linear charge), and propertional distance $\bar{R}=R/W^{1/3} \leq 2m/Kg^{1/3}$. In this paper, research are carried out on acceleration response spectrum of strong explosion of linear charge in near field ($\bar{R}<2m/Kg^{1/3}$), in which buildings are set up according to the actual arrangements of industry, and the seismic effects of explosion on building are measured. Threfore the calculating problems of seismic force of explosion are solved.

2 ARRANGEMENT OF FIELD AND MEASURING POINTS

Experiments are made on geological conditions — granite medium, conglomerate medium and yellow soil medium. The physical mechanical targets of media are shown in table 1.

Tunnels of charge are digged in hills of granit, conglomerate and yellow soil, and alleys are digged for arranging the measuring points in the perpendicular and paraller directions of the tunnels. The ground surface of alleys and tunnels are at the same horizontal level. the mesuring points of acceleration of explosion seismic wave are on the earth surface of alley and in the range of propertional distance $\bar{R}$= 0.2134—2.0759$m/Kg^{1/3}$ (equal to the quantity of charge $\bar{Q}$=4.6860—0.4817 $kg^{1/3}/m$), Tere are 156 points in all.

The energy of explosion is equivalent to 1.69 — 3.50 times of that of natural earthquake.

3 CALCULATION OF ACCELERATION RESPONSE SPECTRUM OF STRONG EXPLOSION SEISM FOR LINEAR CHARGE

While the menmade explosion takes place generally in shallow layer of earth sueface, energy is smaller, time of vibration maintains shorter, decay is faster, vibrating frequency is higher, energy of explosion seism concentrates on high frequency zone (>10 Hz), wave figure of explosion seism hase features of impact vibration, the natural earthquake normally takes place in deep layer of earth surface, energy is larger, time of vibration maintains longer, decay is slower, vibrating frequency is lower,

energy of earthquake concentrates on low frequency(< 10 Hz), wave figure has the features of random vibration. Never the less, both of them have the same vibrating equation and similar mechanism of damage to building. Thus, it is possible to extend the method of calculation of earthquake force from acceleration response spectrum to seismic force of explosion. In this paper, single particle system is researched.

The kinetic equation of single particle system is

$$\ddot{x} + 2\xi\omega^2\dot{x} + \omega x = -a(t) \tag{1}$$

where ξ: damping ratio

ω: circular frequency of self-vibration of single partical system

assume that acceleration $a(t)$ changes in the form of straght line between t_i and t_{i+1}, equation (1) can be rewritten in the incremental form

$$\ddot{x} + 2\xi\omega\dot{x} + \omega^2 x = -a_i - \frac{\Delta a_i}{\Delta t_i}(t-t_i) \tag{2}$$

where
$$\begin{aligned} \Delta t_i &= t_{i+1} - t_i \\ \Delta a_i &= a_{i+1} - a_i \end{aligned} \tag{3}$$

then, the solution of equation (2) is

$$x = e^{-\xi\omega(t-t_i)}\left[c_1 \sin\omega\sqrt{1-\xi^2}(t-t_i) + c_2\cos\omega\sqrt{1-\xi^2}(t-t_i)\right] - \frac{a_i}{\omega^2} + \frac{2\xi}{\omega^3}\frac{\Delta a_i}{\Delta t_i} - \frac{1}{\omega^2}\frac{\Delta a_i}{\Delta t_i}(t-t_i) \tag{4}$$

where $t=t_i$; $x=x_i$; $\dot{x}=\dot{x}_i$, the integral constants are

$$c_1 = \frac{1}{\omega\sqrt{1-\xi^2}}\left[\xi\omega x_i + \dot{x}_i - \frac{2\xi^2-1}{\omega^2}\frac{\Delta a_i}{\Delta t_i} + \frac{\xi}{\omega}a_i\right] \tag{5a}$$

$$c_2 = x_i - \frac{2\xi}{\omega^3}\frac{\Delta a_i}{\Delta t_i} + \frac{a_i}{\omega^2} \tag{5b}$$

Insert constants c_1 and c_2 in equation (4) and at $t=t_{i+1}$, the distance x and speed $\dot{x}$ are

$$\bar{x}_{i+1}=A(\xi,\ \omega,\ \Delta t_i)\bar{x}_i + B(\xi,\ \omega,\ \Delta t_i)\bar{a}_i \tag{6a}$$

where $\bar{x}_i=[x_i \quad \dot{x}_i]$

$$\bar{a}_i=[a_i \quad a_{i+1}]^T \tag{6b}$$

$$A=\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} \qquad B=\begin{vmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{vmatrix} \tag{6c}$$

coefficients $a_{11}, a_{12}, a_{21}, a_{22}, b_{11}, b_{12}, b_{21}, b_{22}$ are fuctions of ξ, ω, Δa_i, and their mathematical expressions are

$$a_{11}=e^{-\xi\omega\Delta t_i}\left(\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i+\cos\omega\sqrt{1-\xi^2}\Delta t_i\right) \tag{7a}$$

$$a_{12}=\frac{e^{-\xi\omega\Delta t_i}}{\omega\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i \tag{7b}$$

$$a_{22}=e^{-\xi\omega\Delta t_i}\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i\right) \tag{7c}$$

$$b_{11}=e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\frac{\sin\omega\sqrt{1-\xi^2}\Delta t_i}{\omega\sqrt{1-\xi^2}} +\left(\frac{2\xi}{\omega^3\Delta t_i}+\frac{1}{\omega^2}\right)\cos\omega\sqrt{1-\xi^2}\Delta t_i\right]-\frac{2\xi}{\omega^3\Delta t_i} \tag{7d}$$

$$b_{12}=-e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\frac{\sin\omega\sqrt{1-\xi^2}\Delta t_i}{\omega\sqrt{1-\xi^2}} +\frac{2\xi}{\omega^3\Delta t_i}\cos\omega\sqrt{1-\xi^2}\Delta t_i\right]-\frac{1}{\omega^2}+\frac{2\xi}{\omega^3\Delta t_i} \tag{7e}$$

$$b_{21}=e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\cdot\sin\omega\sqrt{1-\xi^2}\Delta t_i\right)-\left(\frac{2\xi}{\omega^3\Delta t_i}+\frac{1}{\omega^2}\right)\left(\omega\sqrt{1-\xi^2}\sin\omega\cdot\sqrt{1-\xi^2}\Delta t_i+\xi\,\omega\cos\omega\sqrt{1-\xi^2}\Delta t_i\right)\right]+\frac{1}{\omega^2\Delta t_i} \tag{7f}$$

$$b_{22}=-e^{-\xi\omega\Delta t_i}\left[\frac{2\xi^2-1}{\omega^2\Delta t_i}\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i\right)-\left(\frac{2\xi}{\omega^2\Delta t_i}+\frac{1}{\omega^2}\right)\left(\omega\sqrt{1-\xi^2}\sin\omega\sqrt{1-\xi^2}\Delta t_i+\xi\omega\cos\omega\sqrt{1-\xi^2}\Delta t_i\right)\right]-\frac{1}{\omega^2\Delta t_i} \qquad (7g)$$

At arbitrary time t_i, the absolute acceleration $\ddot{z}_i$ is the sum of earth surface acceleration and acceleration of single particle system, that is

$$\ddot{z}_i=\ddot{x}_i+a_i=-(2\xi\omega\dot{x}_i+\omega^2 x_i) \qquad (8)$$

If distance x_i and speed $\dot{x}_i$ at time $t=t_i$ are known, the distance x_{i+1} and speed $\dot{x}_{i+1}$ at time $t=t_{i+1}$ can be calculated from equation (6a), then, the acceleration $\ddot{x}_{i+1}$ can be calculated from equation (8)

At the beginging of explosion seism, the single particle system is in static state, that is, the initial conditions are $x_0=0, \dot{x}_0=0$. repeat using equation (6a) and (8), the seismic response of single partical system can be worked out step by step. In order to guarantee the accuracy of results calculated, the length of time step should be chosen in such that $\Delta t \leqslant T/10$ (T—natural period of vibration of single partical system), and in this paper, the length of calculating step is chosen $\Delta t=2\times10^{-4}$ second.

In order to diminishing calculating error, the measured time equations of acceleration (a-t figure) are changed into numerical time equations (a-t fiqure). Inputting them into computer, acceleration response spectrum of strong explosion seism for linear charge can then be accuratly calculated. The main results of calculation are introduced below.

1. The individual measured curve of time equation of acceleration is inputted to computer and acceleration response spectrum of explosion seism for linear charge can be calculated under different damping factor such as shown in figure 1.

2. In the medium of granite, the acceleration response spectrums of of near-field strong explosion seism for linear charge are shown in figure 2.

3 The acceleration response spectrum in perpendicular, horizontal radial and horizontal tangential directions are shown in Fig.3, which indicate the near-field strong explosion seism for linear-charge in medium of granite.

4 Under different damping factor, the acceleration response spectrum

of near-field strong explosion seism for linear charge are shown in Fig.4.

5.On different geological conditions (yellow soil, granite, conglomerate), the acceleration response spectrums of near-field strong explosion seism are shown in Fig.5.

6 The acceleration response spectrums under different blasting are shown in figure 6.

Following features of acceleration response spectrum of near-field strong explosion seism for linear charge can be found from the results of calculation shown above,

1. The features of response spectrum

The shape of acceleration response spectrum curve of near-field strong explosion seism is similar to the shape of acceleration response spectrum of natural earthguake, both have a mainpeak, and as envelop line is taken, the peak is changed into a platform and decayed in the form of hyperbola with the increasing of period. The trend of outline of response spectrum is related to acoustic impedance of rock and soil. The smaller the acoustic impedance, the longer moving of peak position in direction of big values of period, that is the width of platform becomes wider. The width of platform is smaller than 0.1 second, in the acceleration response spectrum of near-field strong explosion seism for linear-charge. The position of mainpeak of response spectrum is about the dominate period of rock and soil of earth surface.

2. Influence of horizontal and perpendicular vibration to response spectrum

As shown in Fig.3. the shape, trend and numrical value of both radial and tangential acceleration response spectrum are similar to that of perpendicular acceleration response spectrum, and the curve of perpendicular acceleration reponse spectrum of seism is a little bit bigger than that of both radial and tangential acceleration response spectrum. When the response spectrum is made for design, response spectrums of radial, tangential and perpendicular are sumed up and eventop line is taken, so, influence of radial, tangential and perpendicular vibration have been considered.

3. The influence of damping

As shown in Fig.4, the value of response spectrum peak decreases dastically as the damping factor increasing. For instance, the peak value under damping factor $\xi=0.5$ is about half of the peak value under damping factor $\xi=0$. This indicates that damping has a remarkable effect on decreasing explosion seism. Actulally, damping is related to structure as well as material, and the damping factor increases with the increasing of deformation of foundation, that is the damping factor is related to interaction between rock or soil and structure, so,

normally, the value of damping factor is obtained by experiment.

4. The influence of geological conditions to the response spectrum

As shown in Fig.5, the value of response spectrum is the biggest in yellow soil, then in granite and the least in conglomerate. This means the bigger the acoustic impedance of rock and soil, the smaller the peak value of response, and the smaller the seismic force of explosion to building.

5. The influence of blasting forms to response spectrum

As shown in Fig.6, the value of acceleration response spectrum is the biggest under directional blasting, intermediate under tunnel blasting for linear charge and the least under loosing blasting, so, when the seismic force of explosion is colculated the acceleration response spectrums should be used according to forms of blasting and then the accuracy of calculation can be raised. Under the same form of blasting and geological condition, the value of acceleration response spectrum of near-field is bigger than that of far-field. Nowdays, in China, the data of research about acceleration response spectrum is more in far-field and less in near-field. If the acceleration response spectrum of far-field is used to near-field, the calculated seismic force is smaller, and it may cause results unsafe.

4 THE CALCULATION OF SEISMIC FORCE OF EXPLOSION

As mentioned above, the seismic effect of explosion can be studied with the helps of methods that are used in studying the effects of natural earthquake, when the response spectrum of explosion seism has been worked out, the seismic force of explosion can be calculated directly.

For the single degree of freedom system, the shearing force which acts on the foundation of system is the same as the maximum intertial force which acts on system. In practical application of engineering, the seismic force acted on single particle system can be written in the following form,

$$F = m\ddot{z} = m\,|\ddot{x} + \ddot{\delta}_g|_{max} = \frac{|\ddot{\delta}_g|_{max}}{g} \cdot \frac{|\ddot{x} + \ddot{\delta}_g|_{max}}{|\ddot{\delta}_g|_{max}} \cdot W = k\alpha W \qquad (9)$$

K, seismic coefficient, $k = |\ddot{\delta}_g|_{max} / g$, ratio of maxmum horizontal acceleration of explosion over acceleration of gravity

α , dynamic coefficient, $\alpha = |\ddot{x} + \ddot{\delta}_g|_{max} / |\ddot{\delta}|_{max}$ ratio of maximum acceleration of single particle system over maximum acceleration of earth surface under the seicmic effect of explosion

δ_g , moving distance of earth surface

W, total weight of buildings which produce explosion seismic load.

equation (9)becomes

$$F = \beta W \tag{10}$$

where β , influence coefficient, $\beta = \bar{k}\alpha$, the β-curve of near-field strong explosion for linear charge is shown in Fig.7.

In fact, during the process of explosion, plastic deformation is allowed in the structrue, and at the same time, the unload effect takes place in the structure, this them reduces the seismic force acted on structures; so it is necessary that the equation (10) is multiplied by a struture influence coefficient c which is smaller than 1. The value of coefficient is related to the premitting deformation and ductility of structure. In normal case, $c = 1/\mu \sim 1/\sqrt{2\mu - 1}$ ($\bar{\mu}$- ductility factor). when $\mu = 3\text{-}5$, $c = 0.45 \sim 0.35$ so the equation (10) becomes

$$F = c\beta w \tag{11}$$

where c, structure influence coefficient

reinforced column $c=0.35$

brick column $c=0.40$

reinforced concrete arch $c=0.35$

multi-storey house $c=0.40$

According to the arrangement of industrial production, single-storey and multi-storey buildings are set up in near field-propertional distance $\bar{R} \leq 2.0\ m/kg^{1/3}$, and when the linear charge is explosion, the seismic force of explosion acted on building are measured.Becaus some favorable factors, such as inhibition of foundation and buildings to moving of foundation, interaction between foundation and bualdings and reducing effect of structure measures of anti-shock bualdings to effect of seismic damage can not be expressed in mathematics form, so us the ratio of explosion seismic force calculated by equation (11) over measured explosion seismic force is 1/2 to 1/4, it suites the reason why comprehensive influence coefficiente need to be considered.

Rewrite the equation (11) in normal engineering form,

$$Q_o = c\beta\eta W \quad (12)$$

where Q_o: shearing force on the foudation of structure 10N
c, structure influence coefficient, seeing equation (10)
β, explosion seismic influence coefficient seeing Fig.7.
η, comprehensive influence coefficient
brick column $\eta = 1/2$
reinforced concrete arch $\eta = 1/4$
multi-storey house $\eta = 1/2.5$
W: total weight of buildings which produce explosive seismic load T

$$W = \sum_{i=1}^{n} W_i \quad (13)$$

The horizontal seismic load of particle i is

$$P_i = \frac{W_i H_i}{\sum_{i=1}^{n} W_i H_i} Q_o \quad (14)$$

W_i: weight which concentrated on particle i T
H_i: height of particle i

The explosion seimic force of multiple degree of freedom system can be calculated with the principle of supeposition.

The horizontal seismic load of particle i in viberating mode j of structure is

$$P_{ji} = c\beta_j \gamma_j X_{ji} \eta W_i \quad (15)$$

(number of particle $i=1, 2 \cdots n$; number of mode of viberation $j=1, 2, \cdots m$)

where P_{ji}: horizontal seismic load of particle i in viberating mode j of structure
β_j: seismic influence coefficient which correspouds with natural period T_j of vibrating mode j of structure, seeing Fig.7
X_{ji}: relative horizontal moving distance of particle i in vibrating mode j of structure
γ_j: joining coefficient of vibrating mode j of structure

$$\gamma_j = \frac{\sum_{i=1}^{n} x_{ji} W_i}{\sum_{i=1}^{n} x_{ji}^2 W_i} \qquad (16)$$

c, η: seeing equation (11)

W_i seeing equation (14)

In the point i of structure, as the maximum inner forces produced by each vibrating mode j don't take place at the same time and according to the research of response of earthquake inprobability, the squar root of sum of squares of maximum inner forces of each mode of vibration in point i can be taken as the maximum response of earthquake on point i. So, under the seismic load of horizontal explosion, the structure inner forca S_i produced in point i can be written in the general form

$$S_i = \sqrt{\sum_j S_{ji}^2} \quad \text{(number of mode of vibration } j=1, 2, 3\cdots m; \text{ in normal case } j=1, 2, 3) \qquad (17)$$

shearing force at point i

$$Q_i = \sqrt{\sum_j \left(\sum_{i=1}^{i} P_{ji}\right)^2} = \sqrt{\sum_j \left[\sum_{i=1}^{i} \beta_j \gamma_j X_{ji} \eta W_i\right]^2}$$

$$= \sqrt{\sum_j Q_{ji}^2} \quad (i=1, 1, \cdots n) \qquad (18)$$

shearing force in foundation

$$Q_0 = \sqrt{\sum_j \left(\sum_{i=1}^{n} P_{ji}\right)^2} = \sqrt{\sum_j \left[\sum_{i=1}^{n} c \beta_j \gamma_j X_{ji} \eta W_i\right]^2}$$

$$= \sqrt{\sum_j Q_{ji}^2} \quad (i=1, 1, \cdots n) \qquad (19)$$

bending moment at point i

$$M_i = \sqrt{\sum_j M_{ji}^2} \quad (i=1, 2\cdots n) \qquad (20)$$

bending moment in foundation

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$$M_0=\sqrt{\sum_j M_{0j}^2} \qquad (j=1, 2, \cdots n) \qquad (21)$$

Equation (17) is called equation of canbination of modes of vibration of square root of sum of squares, when bigger intervals are among the former values of frequency of mode of vibration, satisfactory results can be obtained, otherwise error is bigger. The guaranteed efficiency of the canbination method of modes of vibration is more than 96%.

The conbination methods of modes of vibration are different in different countries. In different countries. In Japan thr maximum inner force is taken the sum of obsolute value of maximum response of each mode vibration, and it is absolutly safe. American professor N.M. Newmark points out if the numbers of freedom in system are less than four, the inner force under the effect of natural earthquake is very close to (only a little bit smaler) the sum of obsolute maximum value; If the numbers of freedom degree in system are more than twelve, the inner force under the effect natural earthquake is very close to square root of sum of square of maximum value and if the numbers are between four and twele, the real ineer force is among the values calculated by this two method.

If the method of square root of sum of squares is directly used to calculate the maximum seismic load of explosion equation (15) becomes

$$P_i=c\,\eta\, W_i\sqrt{\sum_j\left[\beta_j\gamma_j x_{ij}\right]^2} \qquad (22)$$

and using the load calculated by equation (22) to calculate the inner force of system, this seismic effect is bigger than the seismic effect calculated by equation (11). There are two reasons for this difference, one is that the modes of vibration except the first mode are alternately changed between positive and nagtive along the height, but equation (22) doesn't express this change feature; The other is that the relation isn't linear relation between structure stress and load, so, it is much more accurate and strict that using the method of square root of sum of squares calculates the inner firce than that using the method of squares root of sum of square calculates load and then calculates inner force.

5. MAIN CONCLUSION

1. According to practical requires of industrial production, experiments of explosion for linear charge have been made. Plenty of accele-

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ration figure of near-field strong explosion seism are abtained in media of granit, conglomerate and yellow soil, when the figures are inputted to computer, the accelerate response spectrum of near-feild strong explosion seism for linear charge can be calculated. This is most meaning for both in theory and in practice for calculating the seismic force of explosion on buildings in near-field($\bar{R} \leqslant 2m/Kg^{1/3}$) and designing proof seism of explosion, so the buildings in near-field explosion are ensured.

2. According to measurement and theoretical analyses of seismic force on single-storey and multi-storey buildings in near-field of explosion seism for linear charge, the comprehensive influence coefficients which are used in calculating equation of seiamic force of explosion are determined for singl-storey and multi-storey buildings. It is very important for quantitative calculation of seismic force of explosion. The error of calculating seismic force of explosion in this paper compared with measuring seismic force of explosion is about 20—30%.

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Table 1 The physical mechanical targets of media*

physical mechanical targets / name	specific gravity g/cm^3	dry volume gravity g/cm^3	porosity %	compressive strength kg/cm^2	tensile strenge kg/cm^2	elastic modle kg/cm^2	Poisson ratio	adhesive force kg/cm^2	friction angle degree
granic	2.65	2.95	2.30	960	22.90	1.4×10^5	0.30	162	41.6
conglomerate		2.58		572	11.00	4.75×10^5	0.22		
soil Q_3		1.55	0.84			2.667×10^3	0.309	0.23	27.5
Soil Q_4						2.083×10^5	0.312	0.39	27.8

* The numbers in table are direct results of testing

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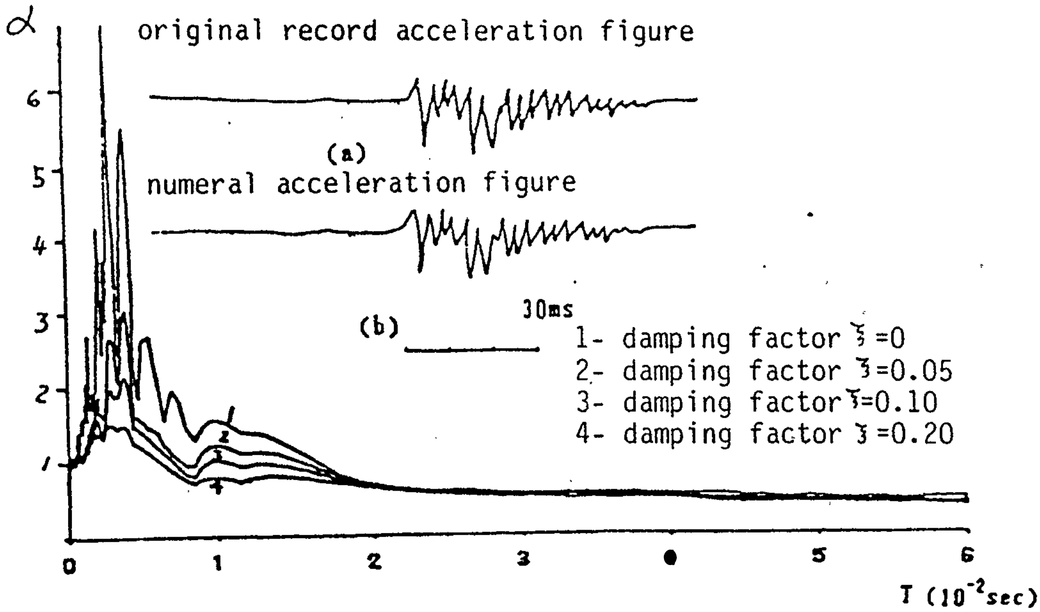

Fig. 1 The acceleration response spectrum of explosion earthquake in granite medium

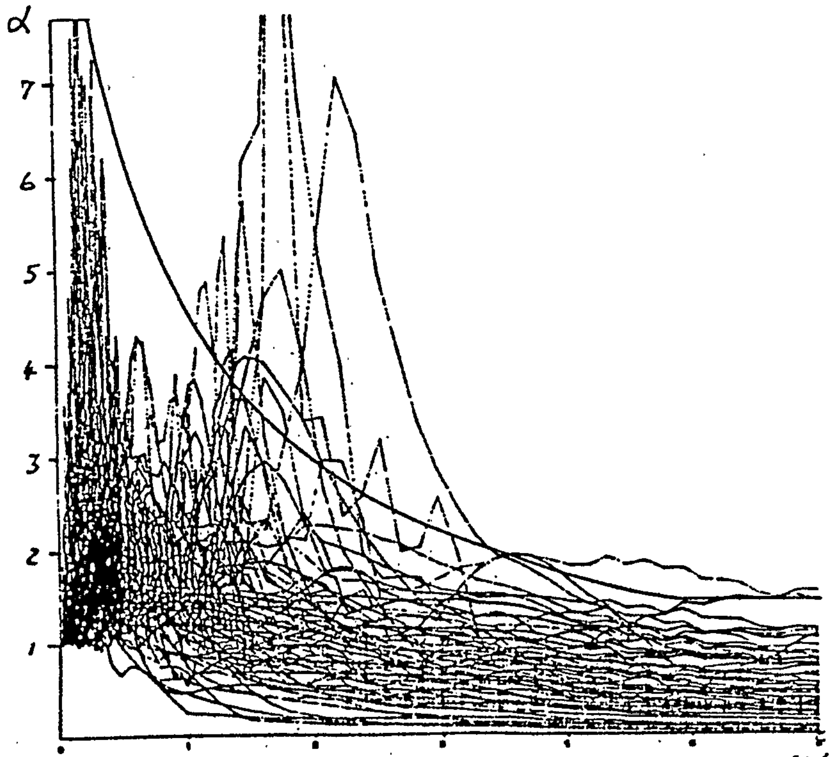

Fig. 2 The acceleration response spectrum of near-field explosion earthquake for linear charge in granite medium

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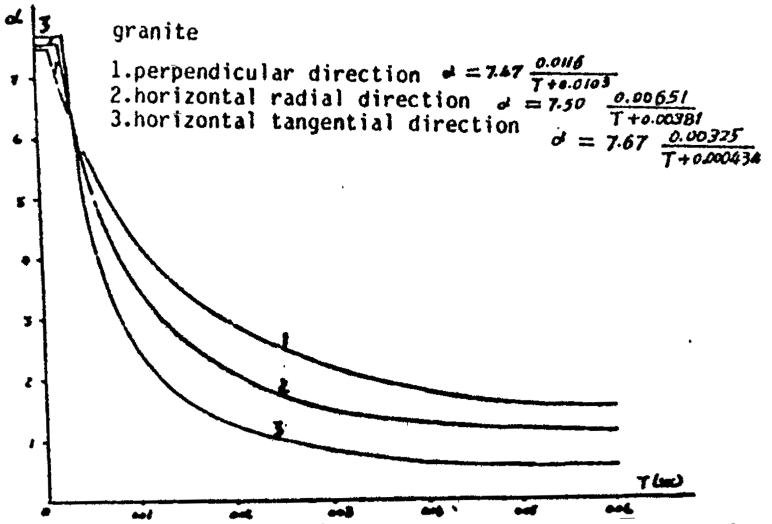

Fig.3 The acceleration response spectrum in the direction of horizontal radial, tangential and perpendicular line (dumping factor $\xi=0$)

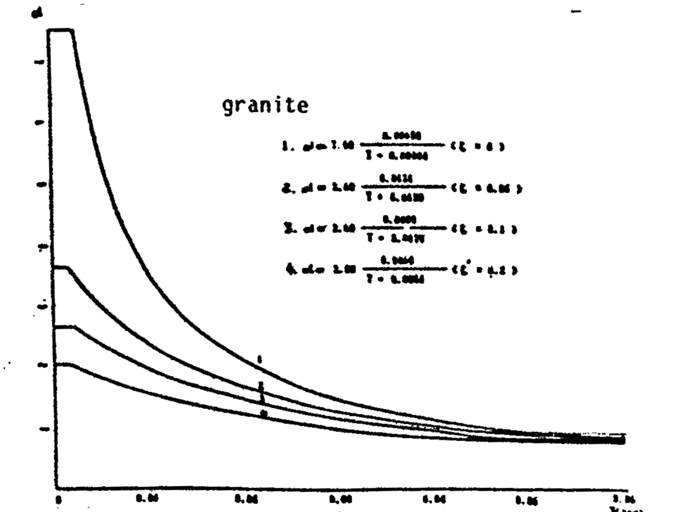

Fig.4 The acceleration response spectrum in different damping factor

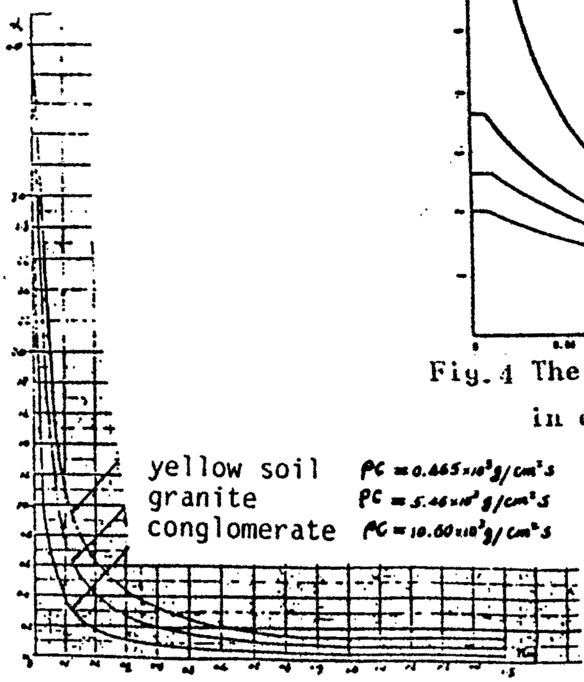

Fig.5 The acceleration response spectrum about granite conglomerate and yellow soil (damping factor $\xi=0$)

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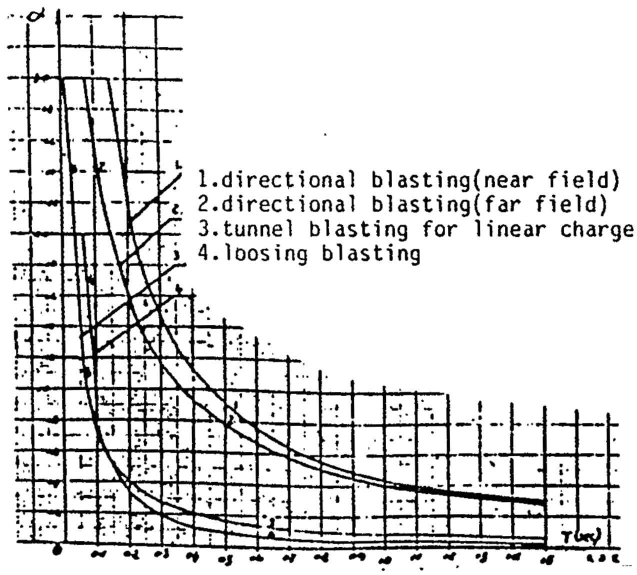

Fig.6 The acceleration response spectrum for different blasting

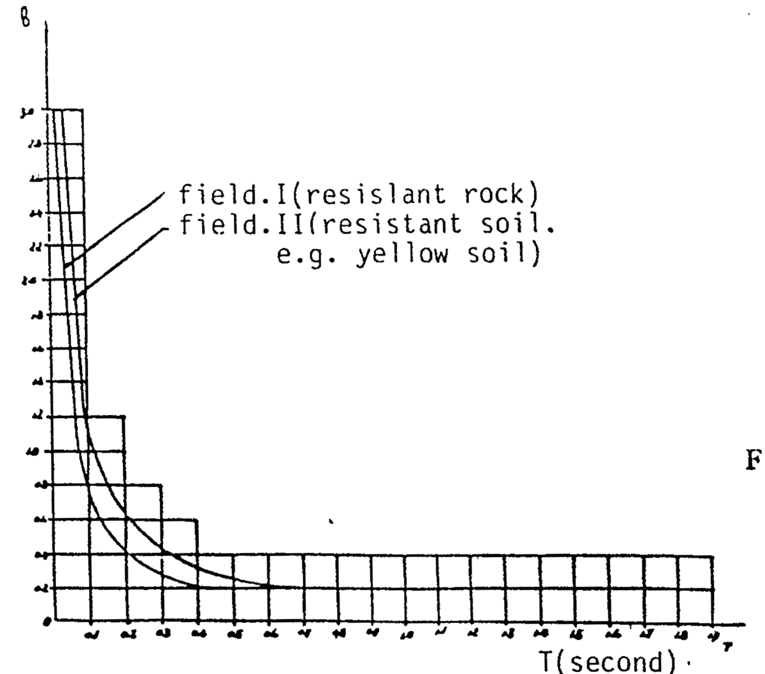

Fig.7 Influence coefficient of explosion seism

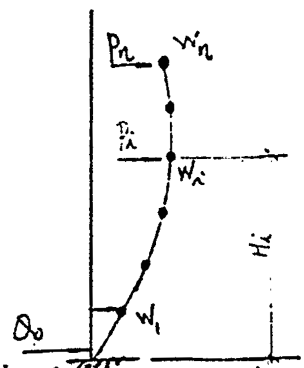

Fig.8 Diagrammatic sketch for calculating